

EVALUATION OF n + C CROSS SECTIONS FOR THE ENERGY
RANGE 1.0E-11 to 150 MeV

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This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 1) evaluation by Fu (Fu90). The following minor modifications were made to the ENDF/B-VI.1 evaluation:

1. The energy range from $E_n = 20$ MeV to 32 MeV was replaced by the LANL evaluation (described below);
2. The elastic, nonelastic, and total cross sections from 19 to 20 MeV were varied to join smoothly with the higher energy values at 20 MeV.
3. The new flag, LCT=3, is used in MF=4,MT=2 to indicate that Legendre polynomials are used below 20 MeV and probability tabulations at higher energies. A small discontinuity exists for MF=4,MT=2 at 20 MeV where the two different representations join. The higher energy evaluation utilizes a tabulation in order to overcome the inaccuracies caused by the ENDF-6 limitation of 20 for the maximum number of Legendre coefficients.

INCIDENT NEUTRON ENERGIES > 20 MeV (12C analysis)

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, alpha particles, gamma rays, and all residual nuclides produced ($A>5$) in the reaction chains. To summarize, the ENDF sections with non-zero data above $E_n = 20$ MeV are:

MF=3 MT= 1 Total Cross Section
MT= 2 Elastic Scattering Cross Section
MT= 3 Nonelastic Cross Section
MT= 5 Sum of Binary (n,n') and (n,x) Reactions
MT=102 Radiative Capture Cross Section (Estimate Only)

MF=4 MT= 2 Elastic Angular Distributions

MF=6 MT= 5 Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

MF=33 MT= 1 Covariance file for total cross section
MT= 2 Covariance file for elastic cross section

MT= 3 Covariance file for nonelastic cross section
MT= 5 Covariance file for composite reaction cross sect.
MT=102 Covariance file for capture cross section

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + C12 and p + C12 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5, MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using either Feshbach, Kerman, Koonin (FKK) theory [Ch93] or the exciton model of Kalbach (Ka77, Ka85). Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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6000 = TARGET 1000Z+A (if A=0 then elemental)

1 = PROJECTILE 1000Z+A

Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	4.908E-01	1.016E+00	4.102E-01	3.449E-02	1.311E-02	0.000E+00	0.000E+00	8.833E-01	1.441E-01
2.300E+01	4.818E-01	9.220E-01	4.135E-01	4.652E-02	2.814E-02	0.000E+00	0.000E+00	8.932E-01	1.357E-01
2.700E+01	4.528E-01	9.040E-01	3.757E-01	6.592E-02	5.422E-02	0.000E+00	0.000E+00	7.662E-01	1.348E-01
3.000E+01	4.338E-01	8.610E-01	3.602E-01	8.299E-02	5.208E-02	0.000E+00	0.000E+00	7.001E-01	1.400E-01
3.500E+01	4.058E-01	7.980E-01	3.337E-01	1.083E-01	5.877E-02	0.000E+00	0.000E+00	5.759E-01	1.491E-01
4.000E+01	3.828E-01	7.280E-01	3.241E-01	1.257E-01	6.229E-02	0.000E+00	0.000E+00	4.950E-01	1.450E-01
5.000E+01	3.428E-01	6.030E-01	3.239E-01	1.425E-01	6.815E-02	0.000E+00	0.000E+00	3.995E-01	1.400E-01
6.000E+01	3.079E-01	5.040E-01	3.165E-01	1.497E-01	6.856E-02	0.000E+00	0.000E+00	3.320E-01	1.304E-01
7.000E+01	2.759E-01	4.280E-01	3.039E-01	1.602E-01	8.000E-02	0.000E+00	0.000E+00	2.964E-01	1.104E-01
8.000E+01	2.439E-01	3.680E-01	2.851E-01	1.591E-01	7.216E-02	0.000E+00	0.000E+00	2.543E-01	9.645E-02
9.000E+01	2.229E-01	3.170E-01	2.826E-01	1.584E-01	7.306E-02	0.000E+00	0.000E+00	2.372E-01	8.436E-02
1.000E+02	2.229E-01	2.620E-01	3.210E-01	1.815E-01	8.528E-02	0.000E+00	0.000E+00	2.482E-01	7.711E-02
1.100E+02	2.298E-01	2.140E-01	3.264E-01	1.802E-01	9.023E-02	0.000E+00	0.000E+00	2.401E-01	8.780E-02
1.200E+02	2.256E-01	1.840E-01	3.334E-01	1.864E-01	9.160E-02	0.000E+00	0.000E+00	2.330E-01	8.615E-02
1.300E+02	2.230E-01	1.550E-01	3.387E-01	1.907E-01	9.477E-02	0.000E+00	0.000E+00	2.271E-01	8.603E-02
1.400E+02	2.227E-01	1.320E-01	3.483E-01	1.972E-01	9.644E-02	0.000E+00	0.000E+00	2.238E-01	8.744E-02
1.500E+02	2.224E-01	1.130E-01	3.546E-01	2.007E-01	9.822E-02	0.000E+00	0.000E+00	2.223E-01	8.895E-02

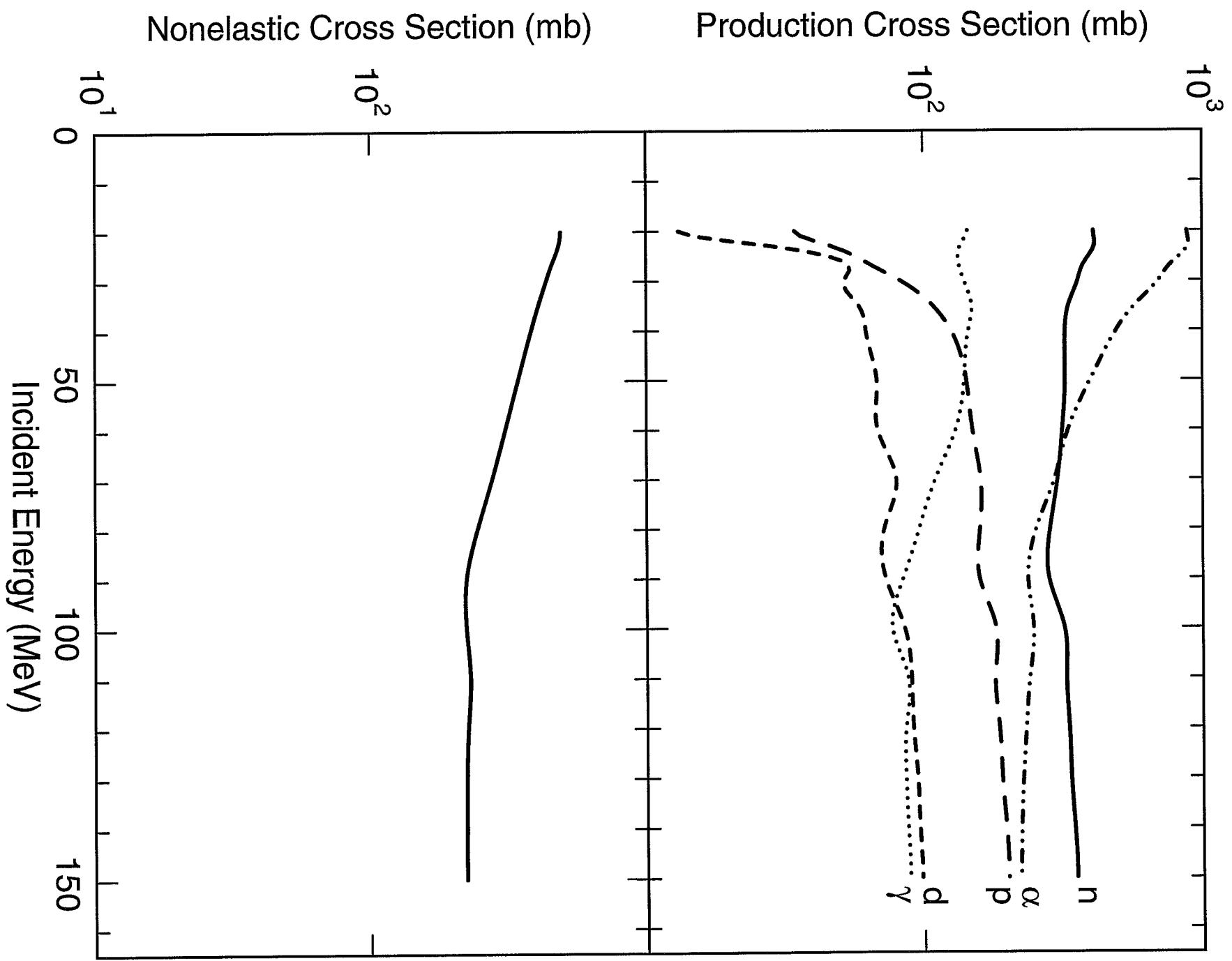
6000 = TARGET 1000Z+A (if A=0 then elemental)

1 = PROJECTILE 1000Z+A

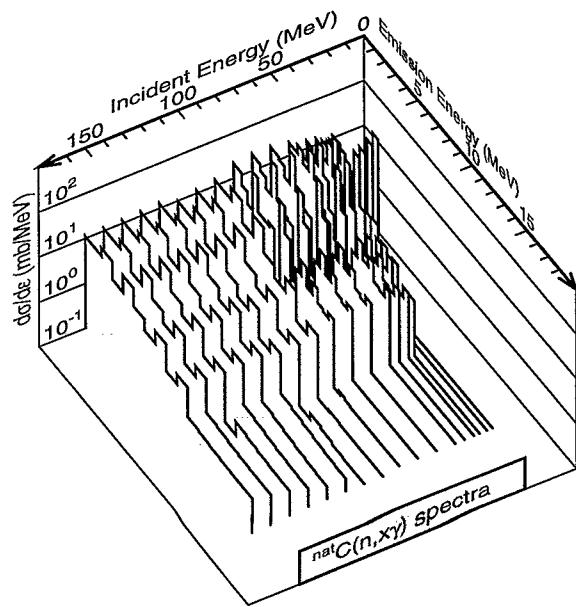
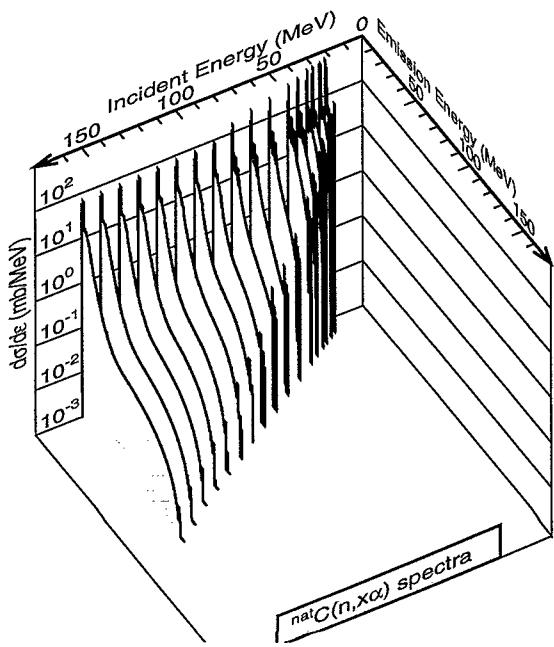
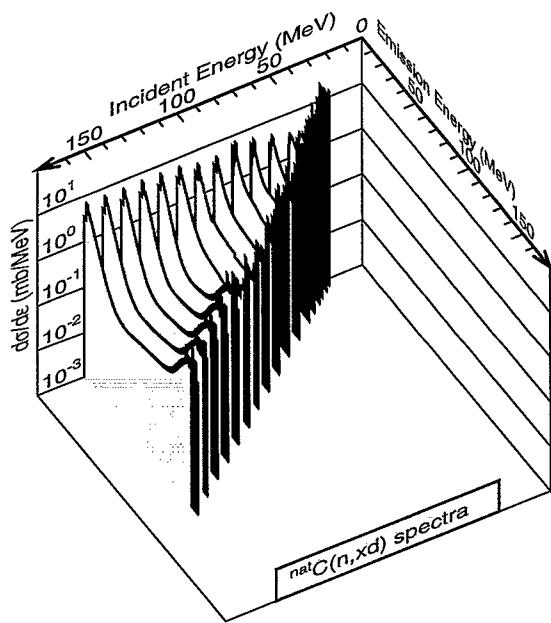
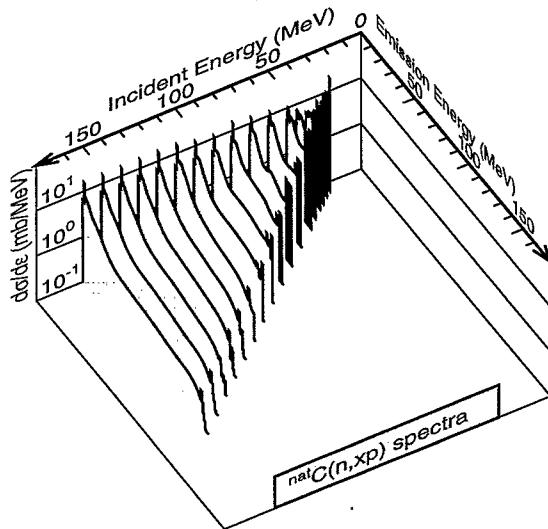
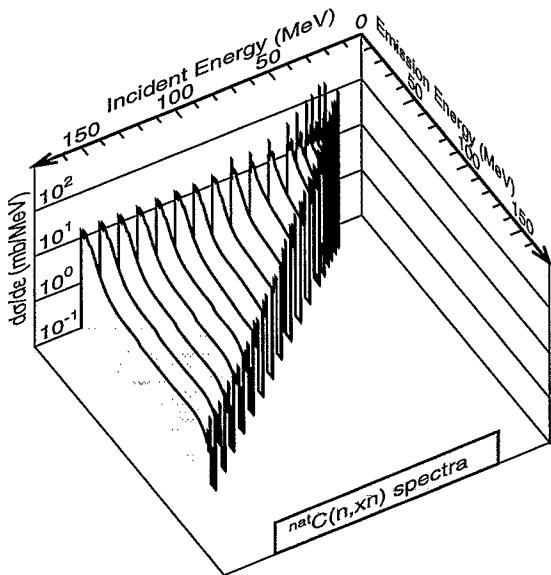
Kearma coefficients in units of f.Gy.m^2:

Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.144E-01	3.360E-02	0.000E+00	0.000E+00	1.913E+00	3.534E-01	5.088E-01	2.923E+00
2.300E+01	1.808E-01	1.174E-01	0.000E+00	0.000E+00	2.140E+00	3.300E-01	4.378E-01	3.206E+00
2.700E+01	3.442E-01	3.250E-01	0.000E+00	0.000E+00	2.078E+00	4.055E-01	4.154E-01	3.569E+00
3.000E+01	5.059E-01	3.483E-01	0.000E+00	0.000E+00	2.149E+00	4.594E-01	3.870E-01	3.850E+00
3.500E+01	8.305E-01	4.939E-01	0.000E+00	0.000E+00	2.037E+00	5.559E-01	3.477E-01	4.265E+00
4.000E+01	1.119E+00	6.254E-01	0.000E+00	0.000E+00	1.908E+00	6.075E-01	3.089E-01	4.569E+00
5.000E+01	1.518E+00	8.790E-01	0.000E+00	0.000E+00	1.682E+00	6.380E-01	2.468E-01	4.964E+00
6.000E+01	1.974E+00	1.052E+00	0.000E+00	0.000E+00	1.415E+00	6.044E-01	2.033E-01	5.249E+00
7.000E+01	2.490E+00	1.331E+00	0.000E+00	0.000E+00	1.419E+00	5.807E-01	1.736E-01	5.994E+00
8.000E+01	2.982E+00	1.354E+00	0.000E+00	0.000E+00	1.271E+00	5.333E-01	1.535E-01	6.294E+00
9.000E+01	3.101E+00	1.478E+00	0.000E+00	0.000E+00	1.285E+00	4.983E-01	1.398E-01	6.502E+00
1.000E+02	3.261E+00	1.715E+00	0.000E+00	0.000E+00	1.447E+00	5.186E-01	1.264E-01	7.068E+00
1.100E+02	3.707E+00	2.460E+00	0.000E+00	0.000E+00	1.387E+00	5.490E-01	8.015E-02	8.183E+00
1.200E+02	4.201E+00	2.646E+00	0.000E+00	0.000E+00	1.408E+00	5.448E-01	6.834E-02	8.869E+00
1.300E+02	4.667E+00	2.948E+00	0.000E+00	0.000E+00	1.448E+00	5.453E-01	5.708E-02	9.666E+00
1.400E+02	5.204E+00	3.163E+00	0.000E+00	0.000E+00	1.479E+00	5.724E-01	4.814E-02	1.047E+01
1.500E+02	5.671E+00	3.442E+00	0.000E+00	0.000E+00	1.515E+00	5.975E-01	4.075E-02	1.127E+01

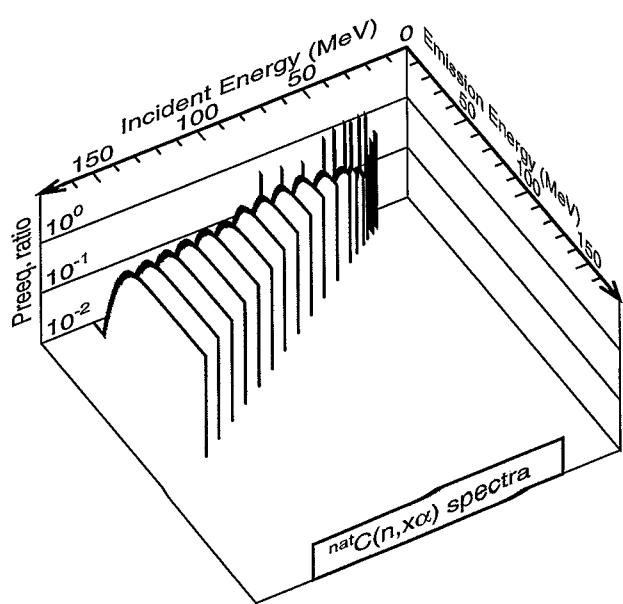
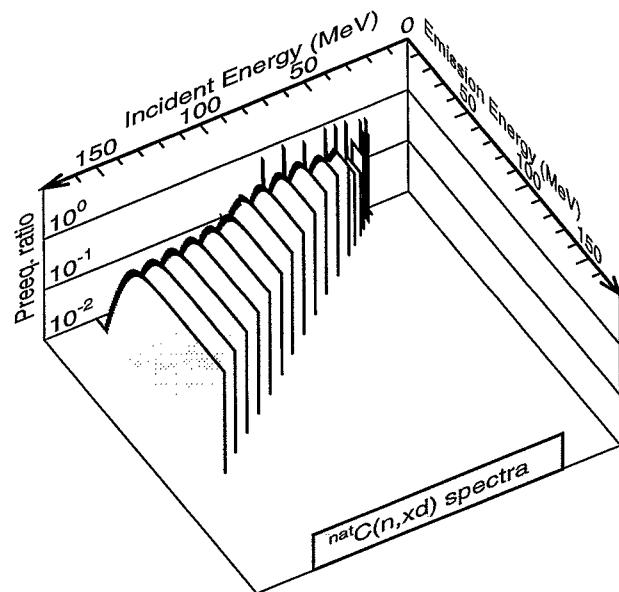
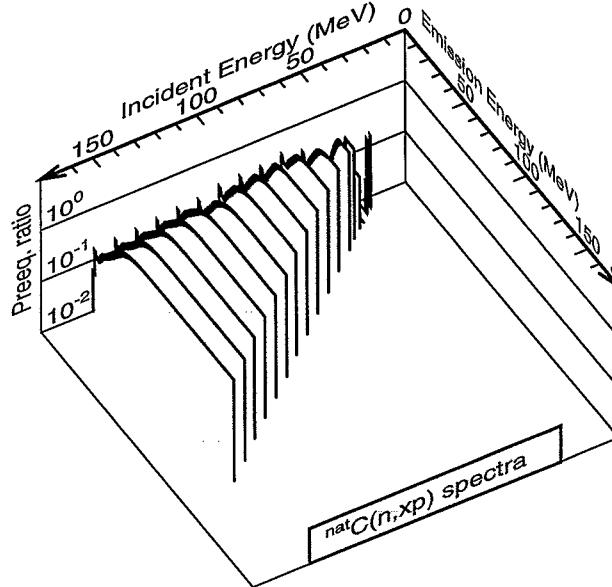
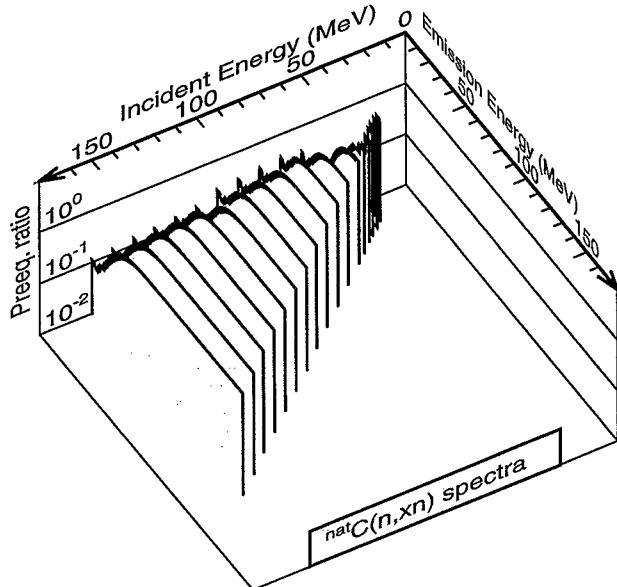
$n + {}^{nat}C$ nonelastic and production cross sections



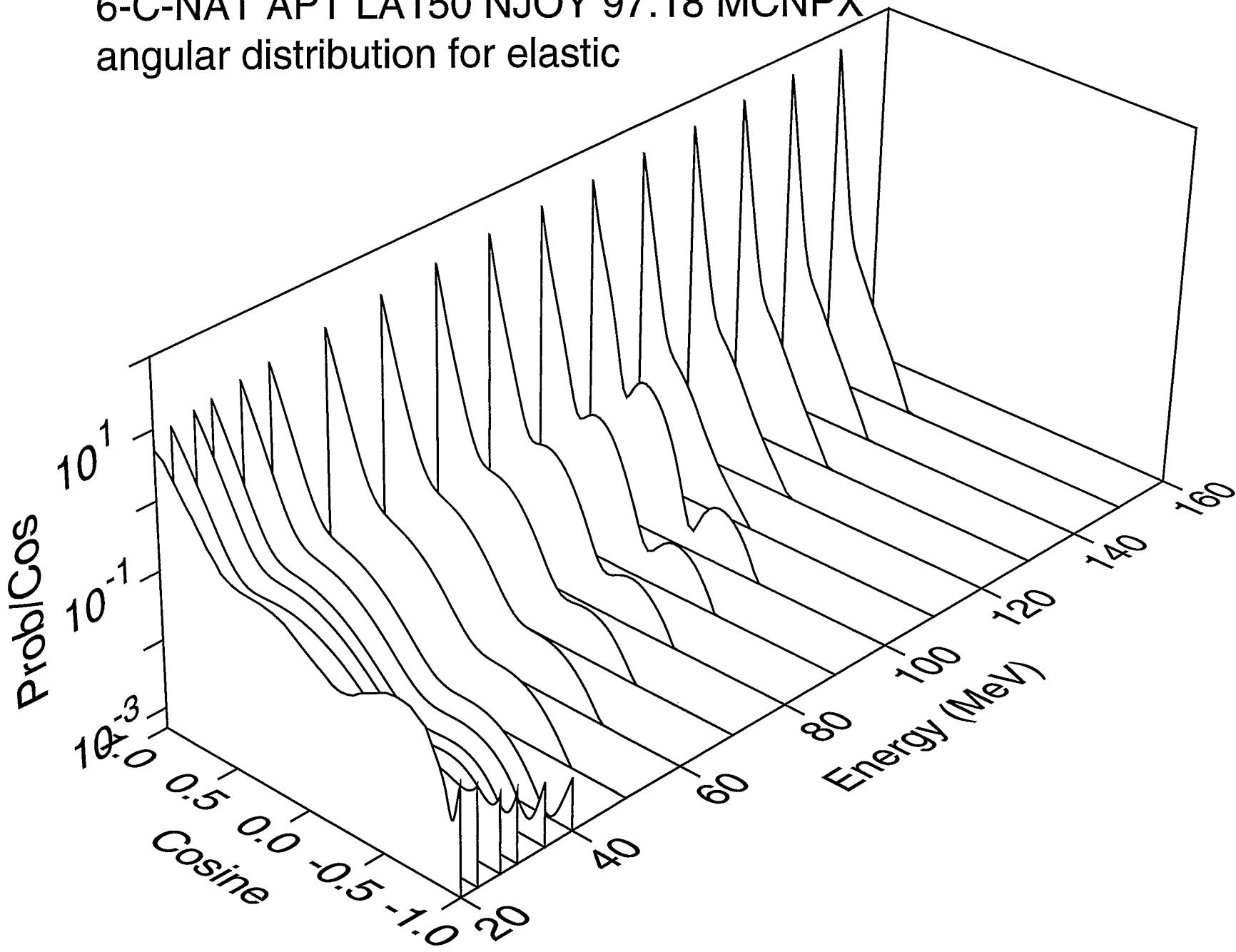
$n + ^{nat}C$ angle-integrated emission spectra



$n + ^{nat}C$ Kalbach preequilibrium ratios

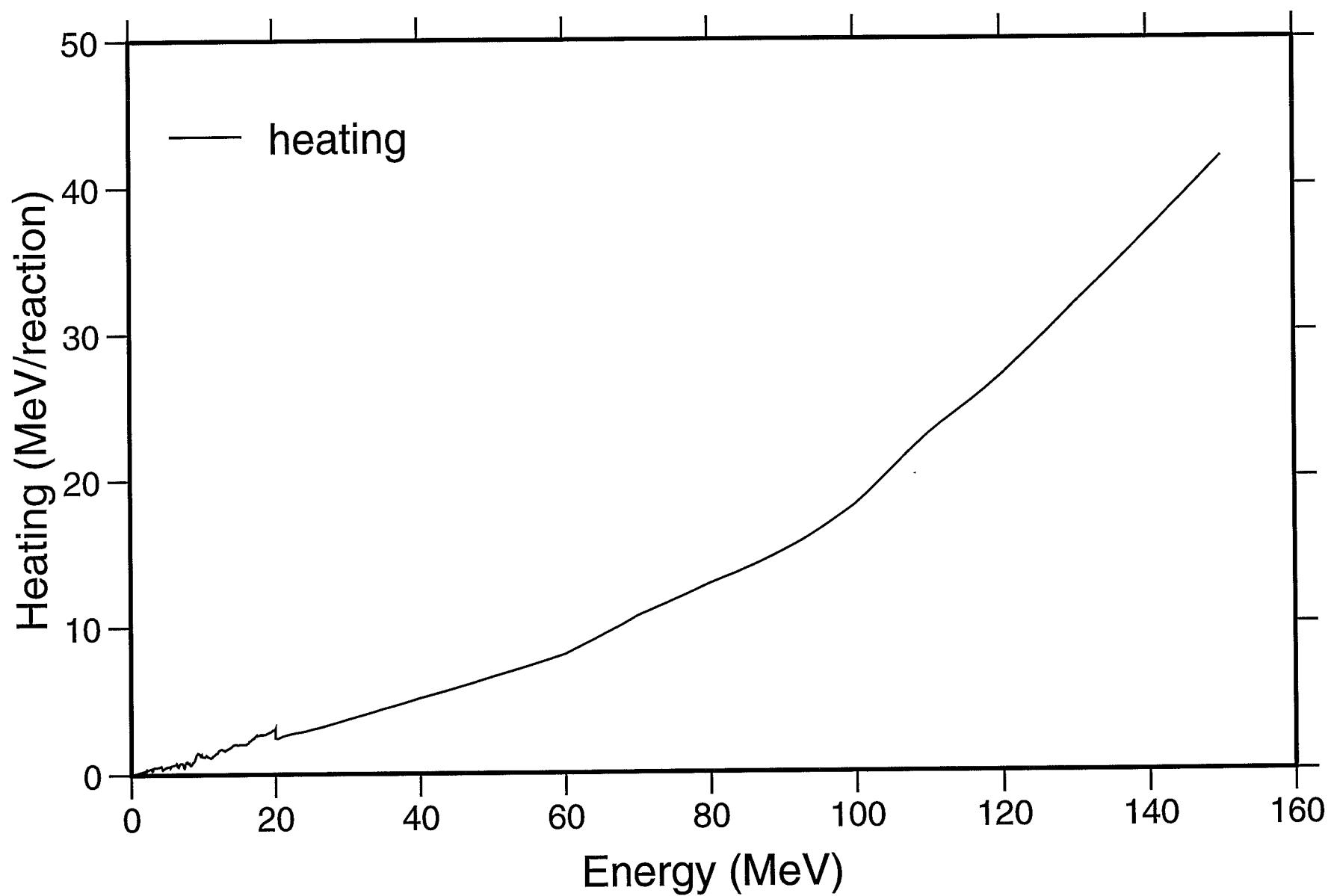


6-C-NAT APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic



6-C-NAT APT LA150 NJOY 97.18 MCNPX

Heating



6-C-NAT APT LA150 NJOY 97.18 MCNPX

Damage

